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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Some Problems
Associated with Lubrication
of Large Engines

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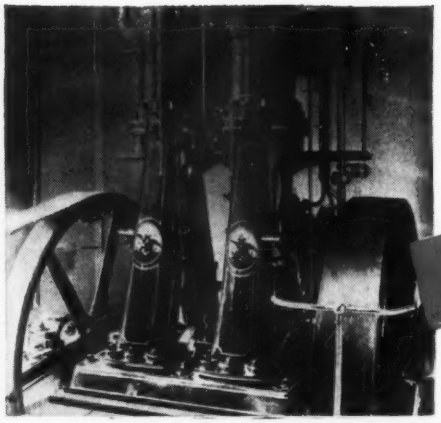
TEXACO PETROLEUM PRODUCTS



DIESELS

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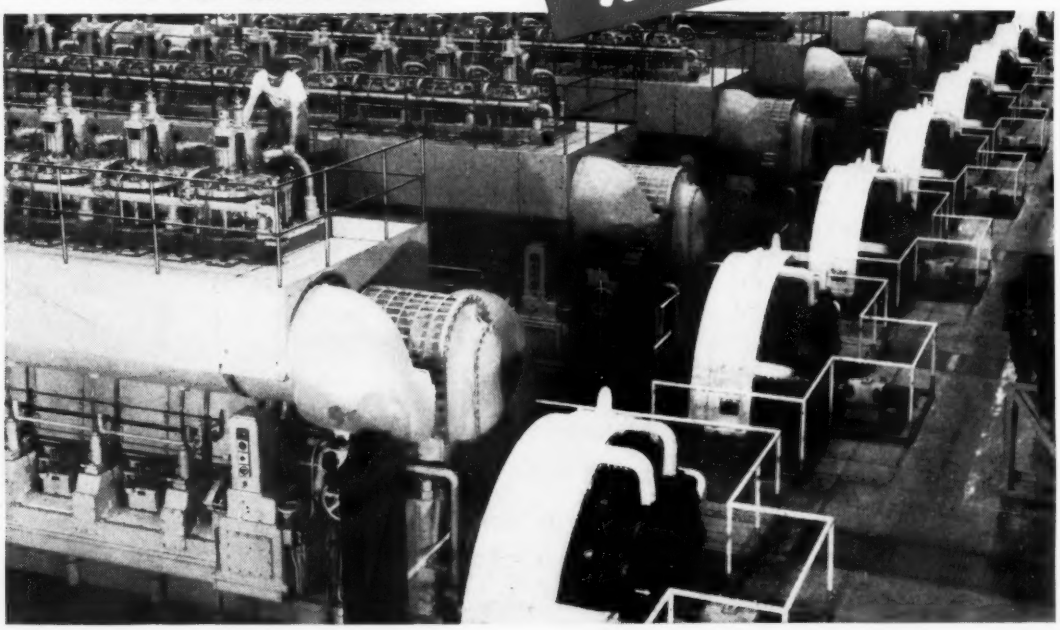
AND NOW . . .



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LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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Some Problems Associated with Lubrication of Large Engines

It is generally accepted that "water and oil won't mix". Fifty years ago the first diesel engine, the first large internal combustion engine operated in this country, was lubricated with a mixture of oil and water, mostly the latter. The crankcase was filled with water up to the lower level of connecting rod travel and on top was added about 2" of a heavy mineral cylinder oil. Crankshaft and piston pin bearings were splash lubricated with this oil and water mixture. Actually, the water, which quickly formed an emulsion with the oil, acted as a cooling medium and by its evaporation kept bearings and other engine parts at desired temperature levels.

Water is still a factor in the lubrication of modern large engines and one which must be contended with from several different angles. In addition, there are other problems associated with lubrication of large engines. It is the purpose of this article to discuss from a practical viewpoint some of the more important of these.

CYLINDER LUBRICATORS

Many of the larger engines are equipped with dual lubrication systems; i.e. pistons and cylinders are lubricated by direct injection of fresh cylinder oil and the remainder of the engine is lubricated with crankcase oil. In some designs, one oil can be used to lubricate cylinders and crankcases, the oil being pumped from the latter through filters to lubricators which in turn feed it to the cylinders. In other designs only new oil is handled by the cylinder lubricators. In either case, each engine cylinder is equipped with one or more sight feed lubricators located near the top of piston travel. The term sight feed means that oil delivery in drop form can be observed through sight glasses containing a transparent liquid through which the oil is pumped. Knowing the approximate oil drop size, some idea of how much oil is being delivered to engine cylinders can be estimated from Figure 1.

Water or mixtures of water and glycerine are the most common fluids used in sight glasses of cylinder lubricators. Glycerine is used at locations where the ambient temperatures may drop below the freezing point of water. Straight mineral oils can be fed through water and water-glycerine solutions for long periods of time without undue carry-over of the solution. The same does not always hold true when additive oils, particularly those containing detergent or dispersant components, are used for cylinder lubrication. Additives used in such oils make the oils more water sensitive than straight mineral oils. This means that heavy duty detergent oils when fed through water or water-glycerine solutions in sight feed lubricators can

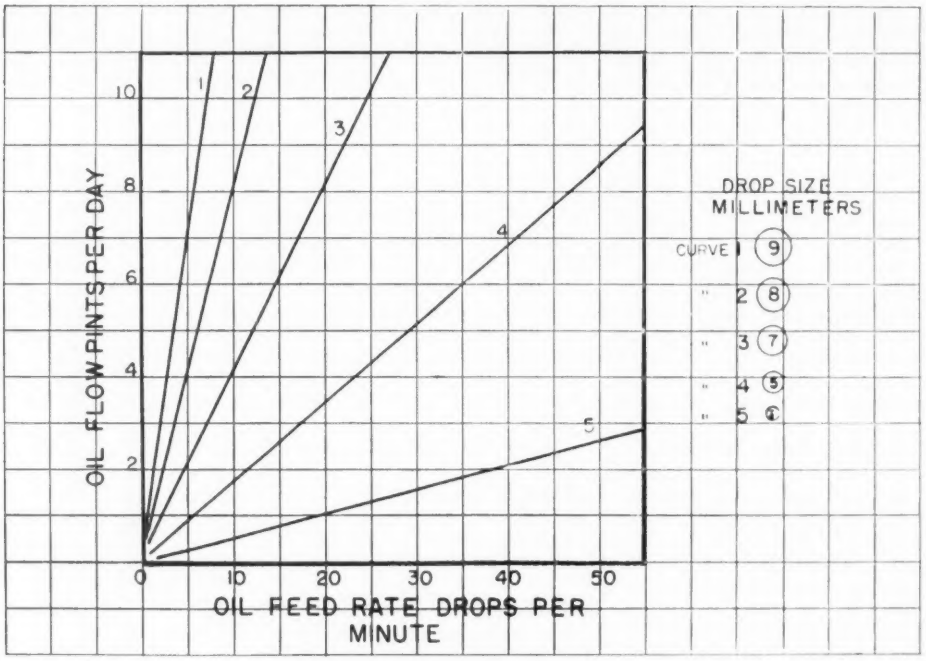

Figure 1

result in any one or all three of the following effects:

1. Excessive carryover of solution due to absorption of the oil.
2. Clouding of the solution due to reaction with the oil additives.
3. Larger oil drop size due to low interfacial tension between the solution and oil. (See Table A).

TABLE A
Interfacial Tension Data

Product (SAE 30 Grade)	*Interfacial Tension dynes/centimeter*
Heavy Duty Oil A	5.3
Heavy Duty Oil B	10.6
Straight Mineral Naphthene	31.6
Straight Mineral Paraffin Residual	36.5
Straight Mineral Paraffin Distillate	39.4

It is evident from the foregoing that feeding additive oils, containing detergents, through sight glass lubricators poses a problem for operators of large engines. Certainly, it is a time consuming and messy job to have to remove and clean numerous small sight glasses more often than necessary to say nothing of the down time on the engines involved. Such a problem is not difficult to solve, however, and lubricator solutions have been found which will provide the desired services for particular additive oils. Figure 2 illustrates one type of laboratory apparatus which is used for the development of improved lubricator fluids. Table B lists some representative results using this equipment.

TABLE B
Sight Feed Lubricator Tests
Heavy Duty Oil A

Solutions	*Solution Carryover inches/100 hours*
Water	0.371
Calcium chloride	0.195
Sodium chloride	0.438
Calcium Nitrate	0.115
Ethylene Glycol	1.228
Barium chloride	0.127
50:50 glycerine and water	6 (Approx.)

Unfortunately, no one lubricator solution has been discovered that will work acceptably with all makes and types of additive oils. In addition, it does not appear probable that the ideal solution will be developed in view of the great variety of chemicals that are and will be used in additive oils of the heavy duty, Supplement I and Series II classifications.

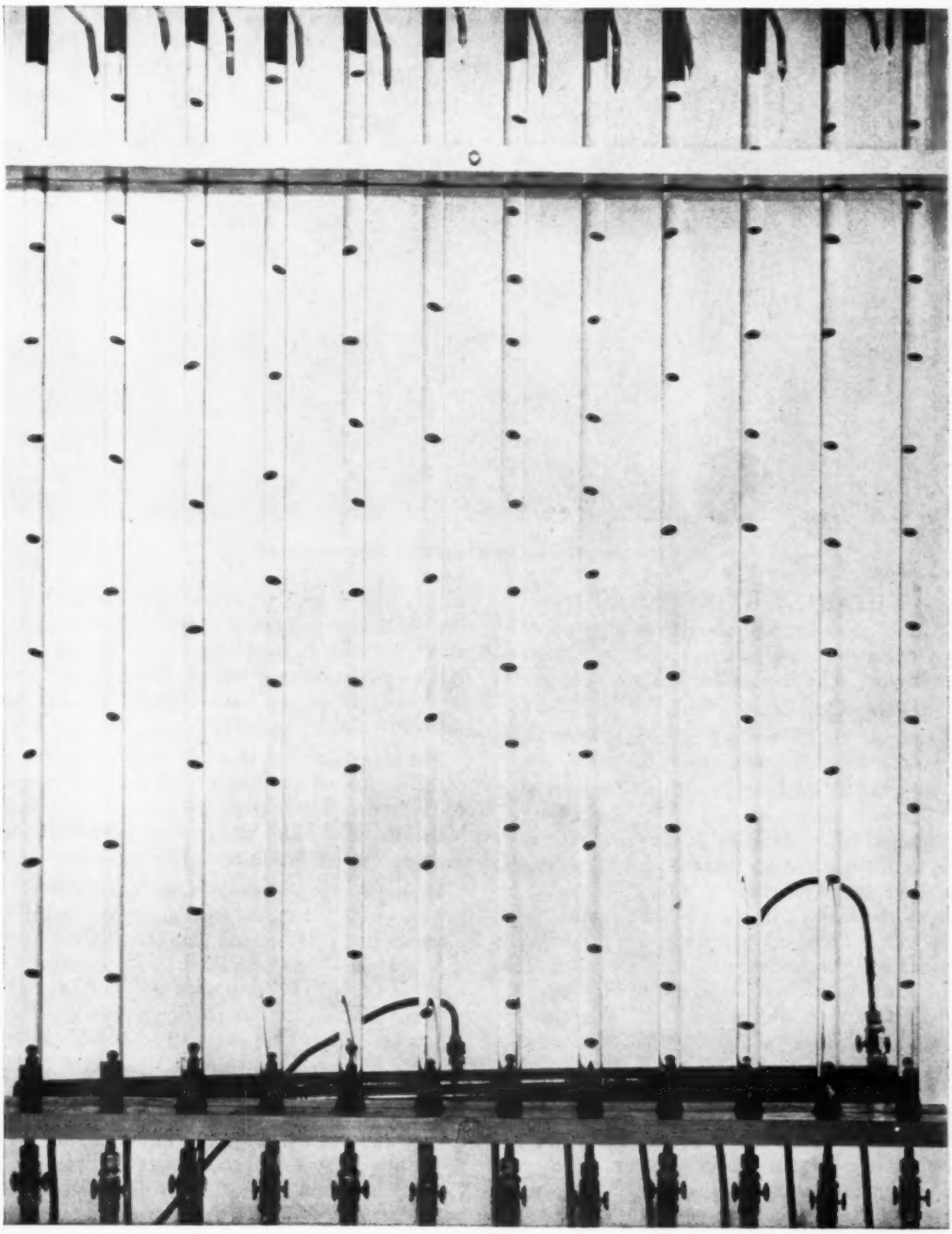

Figure 2—Lubricator Solution Tester

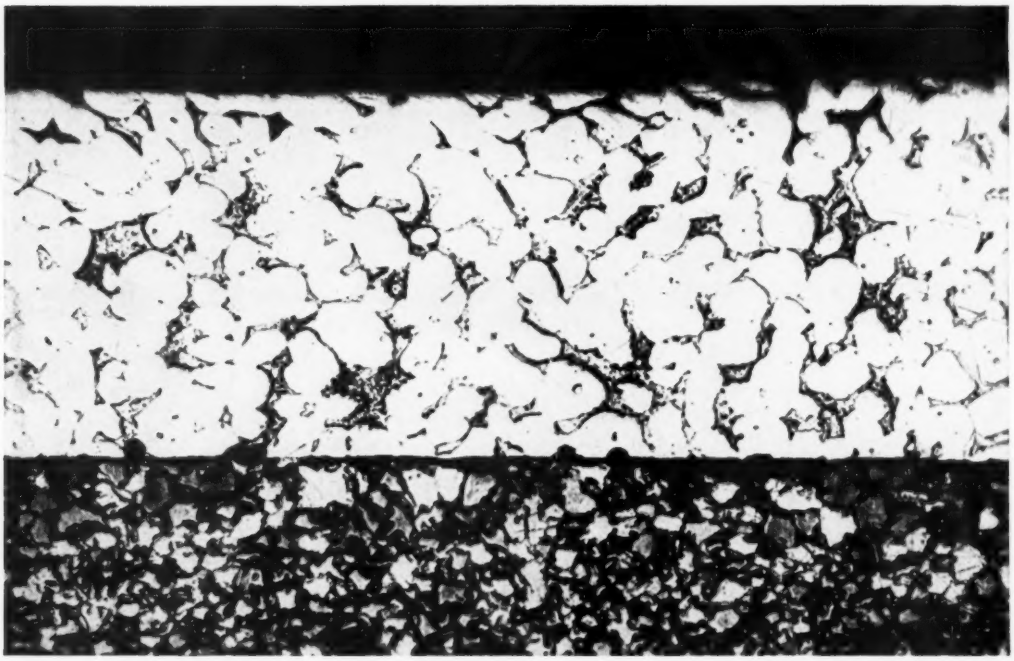

Figure 3—Copper-Lead Bearing—Slight Corrosion (200X)

BEARING CORROSION

Bearing corrosion has never been a problem of major concern to manufacturers or operators of large engines. The reasons for this are:

1. Relatively low bearing loads.
2. General use of bearings relatively insensitive to corrosion such as tin base babbitt.

For the most part bearing corrosion is associated with bearings containing lead either in alloy form, such as lead base babbitt or in the pure state as in the case of dispersed lead in copper-lead mixtures. Pure lead is easily, though slowly, dissolved by some of the lower molecular weight organic acids which result from oil oxidation. Bearings which contain lead in pure form are therefore much more readily corroded than those in which lead has been alloyed with such elements as tin, antimony or silver. Table C lists the more commonly used bearing materials and it will be noted that all but a very few can be corroded as a result of oil deterioration. All lead-containing bearings with the exception of tin base babbitt and bronze are corrodible as well as are those made from silver.

It is generally understood that the term corrosion involves chemical reaction. In the case of bearings containing lead, this is the dissolving of lead by low molecular weight organic acids as explained above. Figures 3 and 4 are photomicrographs which illustrate cases of slight and severe corrosion of copper lead bearings. The grey areas in the copper-lead structure represent lead while the white areas represent copper. Note that only a small amount of lead has been removed at the surface of the bearings shown in Figure 3 whereas practically all of the lead is gone from the bearing illustrated by Figure 4.

For silver bearings it is the chemical conversion of silver to silver sulfide followed by removal of the sulfide material in much the same way that household silverware deteriorates over the course of time. Figure 5 illustrates this condition.

In large engines considerable quantities of oil are required for crankcase lubrication. Most engines in this category use straight mineral oil for this purpose — not only because it is more economical but also because with good filtration it is general practice not to change oil unless it becomes excessively contaminated with fuel or water or until engines are overhauled. Straight mineral oils used for crankcase lubrication are derived from either naphthenic or paraffinic stocks. Each type of oil is subject to oxidation but the results of oxidation differ in so far as their effect on bearing corrosion is concerned. Paraffin distillate oils initially oxidize to form low molecular weight organic acids which readily dissolve lead from lead-containing bearings. Naphthene base oils oxidize to form sludges which have a tendency to coat bearing surfaces with varnish or lacquer thereby protecting bearings from possible attack by organic acidity.

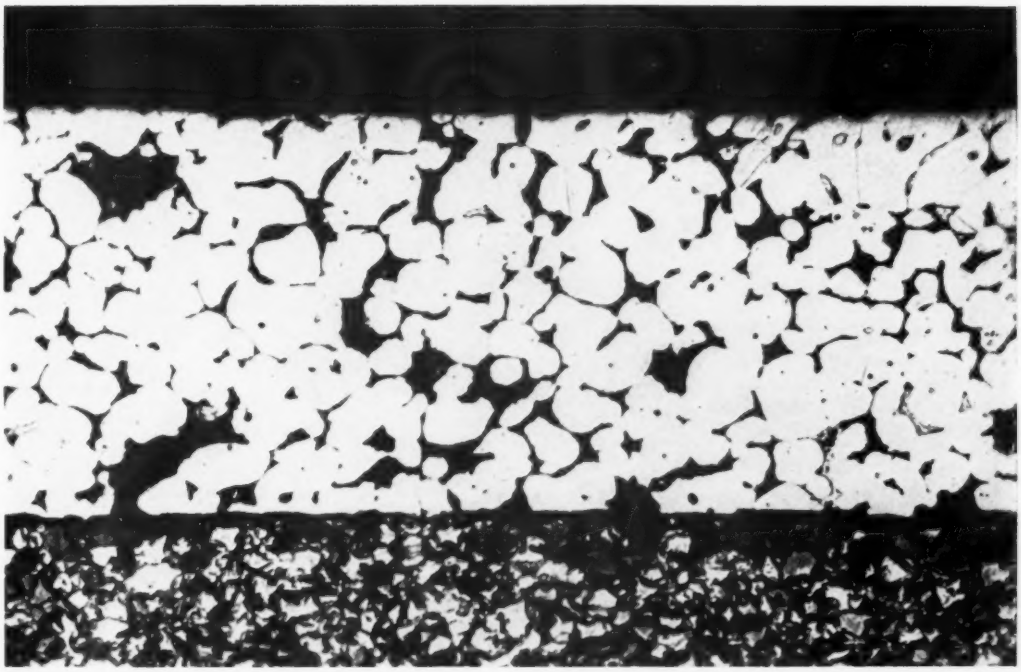

Figure 4—Copper-Lead Bearing—Severe Corrosion (200X)

TABLE C
Bearing Corrosion Properties

Bearing Metal	*Composition*	*Remarks*
Lead or lead-tin coatings	Pure lead or with up to 10% tin	Pure lead easily corroded. 6% tin prevents corrosion. Some additive oils in presence of water, corrosive to lead-tin coatings.
Lead-base babbitt	70-90% lead plus tin and antimony	Added tin and antimony reduces corrosiveness.
Tin-base babbitt	80-90% tin plus copper and antimony	Non-corrosive.
Silver-hardened lead	Lead-base babbitt with 2-5% silver	Added tin, antimony and silver reduces corrosiveness.
Arsenic-hardened lead	Lead-base babbitt plus 1-3% arsenic	Added tin and antimony reduces corrosiveness.
Calcium-hardened lead	Lead with small amounts of tin and calcium	Corrosive. Presence of water not helpful.
Cadmium	Cadmium with small amounts of nickel or silver	Corrosive with badly oxidized oil.
Copper-lead	60-75% copper, balance lead	Corrosive — lead present in pure state.
Silver	Either pure or with small amount of lead	Non-corrodible except by certain types of additives.
Aluminum	90-95% aluminum, balance tin	Non-corrosive.
Lead-bronze	75-85% copper, balance tin and lead	Non-corrosive.

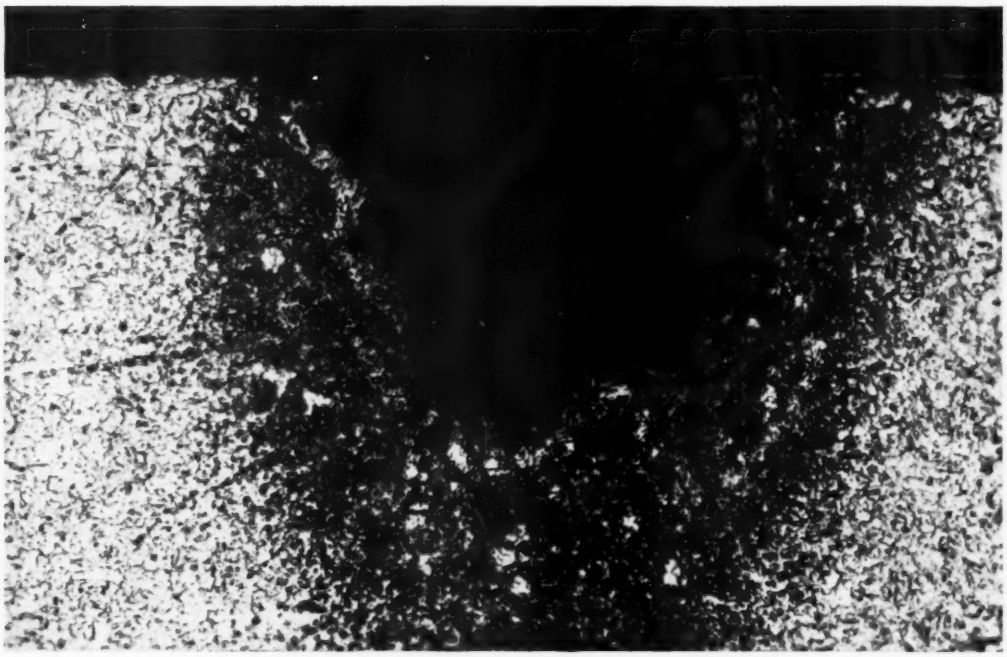

Figure 5—Silver Bearing—Moderate Corrosion (250X)

While naphthene oils are potentially less corrosive to leaded bearings than paraffin distillates, the latter type is preferable in engines where crankcase oil temperatures run above 150°F. because of their better inherent ability to resist thickening or viscosity increase in service.

As a matter of practical application, there are many engine crankcases lubricated with naphthene oils at crankcase oil temperatures at or below 150°F. with excellent results. In such cases, bearing corrosion is not a problem even though bearings of the copper-lead type are in use.

A minor and little recognized phase of bearing corrosion involves oil contaminated with water. While oil and water do not get along too well together, some oils are more affected by water contamination than others in so far as bearing corrosion is concerned. Table D shows pertinent information along this line.

It will be noted that some additive type oils, when contaminated with water, corrode lead and lead-tin materials to a much greater degree than others.

While bearing corrosion has not been and is not a problem for present day operators of large engines, such a possibility must not be overlooked with the advent of new and higher output engines. Guarding against bearing corrosion is a lubrication responsibility of bearing and engine manufacturers along with the oil industry.

CRANKCASE EXPLOSIONS

The occurence of crankcase explosions has long been a hazard to the safe operation of large engines. Although some explosions have been of little consequence, others have resulted in serious injury and death to operating personnel, as well as expensive property damage.

TABLE D
Corrosion Test Results
Weight Loss — mgs.

	Pure Lead		*90:10 Lead-Tin*	
Oil	*No Water*	*2% Water*	*No Water*	*2% Water*
Heavy Duty A	0.0	0.5	0.0	0.0
Heavy Duty B	1.0	15	0.3	0.5
Heavy Duty C	1.1	34	0.0	1.0
Heavy Duty D	0.0	50	0.0	0.3
Heavy Duty E	2.0	75	0.5	29.5

Crankcase explosions are caused by ignition of the crankcase atmosphere by some overheated engine part or by flame torching past a piston. Oil droplets exposed to overheated surfaces or flame vaporize readily and when sufficient vaporization has taken place so that the surrounding mixture is in the inflammable range, ignition in the crankcase can occur. After ignition, the explosion propagates throughout the crankcase by the vaporization and subsequent ignition of the adjacent layers of oil particles in much the same manner as combustion takes place in any internal combustion engine. Generally, an initial explosion occurs first with sufficient energy to blow out crankcase doors, immediately followed by a second explosion of greater intensity. It is the second explosion that causes the major damage. Clouds of white smoke issuing from around crankcase doors and openings, excessive engine vibration and noise are indications of an impending explosion.

Under normal operating conditions, the atmosphere in an engine crankcase is primarily air charged with oil particles of various sizes sprayed and thrown from moving parts. Table E shows composition of crankcase atmosphere samples taken from three different diesel engines.

Note the absence of hydrocarbon gases. This is explained by the fact that the vapor pressure of any oil, naphthenic, paraffinic, or heavy duty is too low at normal operating temperatures for there to be any measurable quantity of oil vapor present in the crankcase above the oil level. Diluting crankcase oil with distillate fuel has little effect upon vaporizing tendencies at crankcase temperatures.

Table F shows composition of crankcase atmosphere samples taken from three different dual-fuel or gas-diesel engines. Here a small quantity of hydrocarbon gas was found in two of the three cases but on the basis of inflammability limits for mixtures of combustible gases (approximately 5% minimum in air) the concentration is too low to be in the inflammable range.

Presence of natural gas in crankcases of dual-fuel or gas-diesel engines coupled with absence or minor traces of carbon dioxide suggests that most piston blowby occurs during the compression stroke. With increased ring and cylinder wear, increase in blowby of natural gas could possibly result in an inflammable gas-air mixture in an engine crankcase in addition to the potential inflammable crankcase oil vapor air mixture.

Figure 7 illustrates a laboratory explosion tube apparatus which has been used to determine causes of engine crankcase explosions. Extensive test work with this apparatus along with detailed field investigations show that there are no significant differences in the minimum ignition temperatures of oils commonly used for lubrication of large engines. In addition, there is no appreciable lowering of the minimum ignition temperature of oil when diluted with up to 20% diesel fuel. These conclusions are verified by the data shown in Table G.

This means, therefore, that the possibilities of crankcase explosions occurring have to be recognized. It is not practicable to build engines in such a way that air is completely eliminated from the crankcase so that no oxygen will be available to

TABLE E
Composition of Diesel Crankcase Atmosphere

Non-Condensible Gases *Percent Volume*	*600 HP* *Engine*	*3000 HP* *Engine*	*3000 HP* *Engine*
Oxygen	20.35	20.29-20.89	20.89
Carbon Monoxide	0	0	0
Carbon Dioxide	0	0.1 - 0.7	0.1
Hydrocarbon Gases	0	0	0
Nitrogen and Inert Gases	79.65	79.01	79.01

TABLE F
Composition of Dual-Fuel Crankcase Atmosphere

Non-Condensible Gases *Percent Volume*	*650 HP* *Engine*	*1220 HP* *Engine*	*3200 HP* *Engine*
Oxygen	18.9	20.7	20.8
Carbon Monoxide	0	0	0
Carbon Dioxide	0.7	0	0
Hydrocarbon Gases	3.9	1.5	0
Nitrogen and Inert Gases	76.5	77.8	79.2

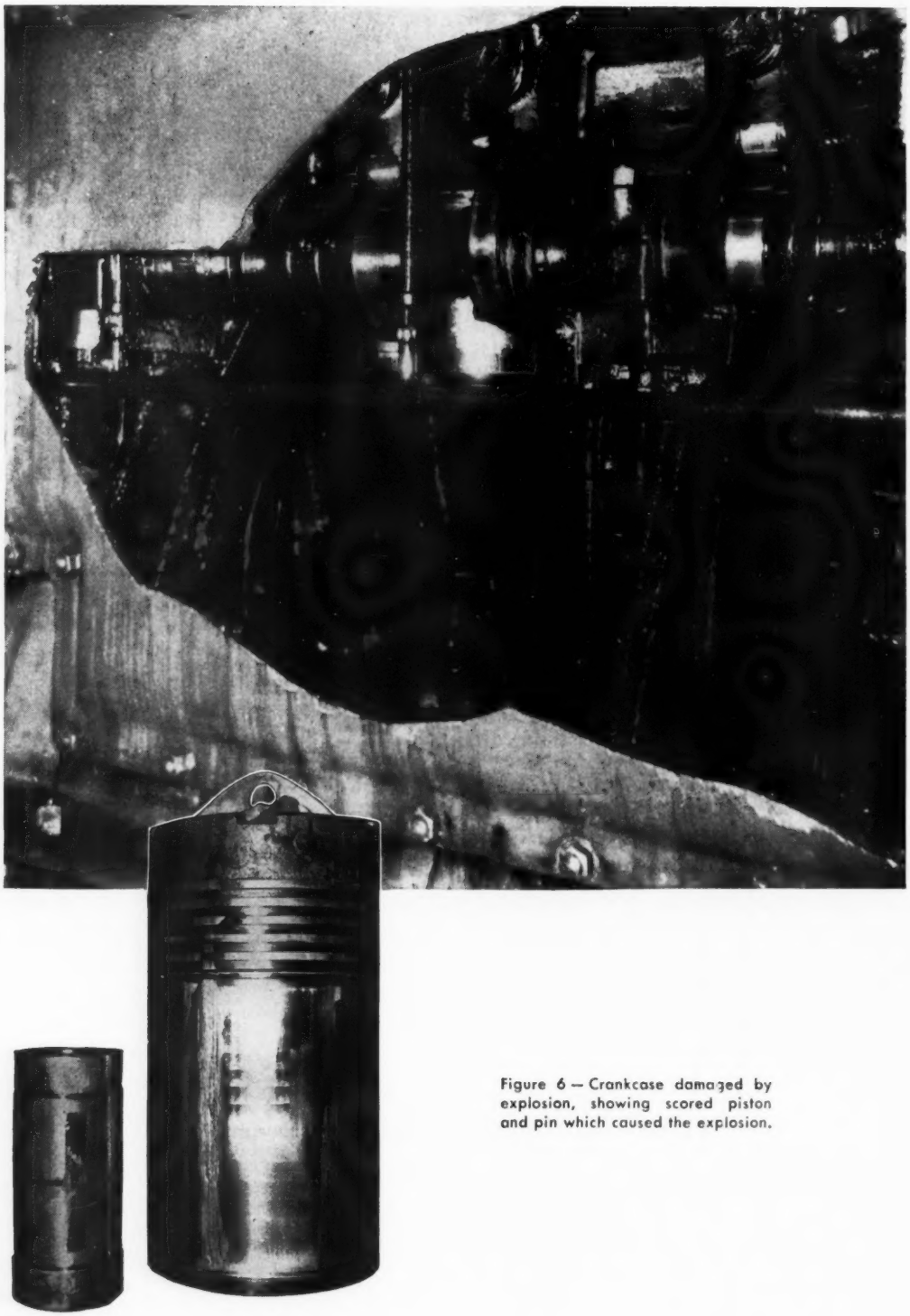

Figure 6 — Crankcase damaged by explosion, showing scored piston and pin which caused the explosion.

support combustion when a hot spot vaporizes the oil droplets. Nor is it feasible to expect that hot spots can be prevented from occurring because of some engine malfunctioning. Consequently, the effects of possible crankcase explosions have to be reckoned with by providing some means of preventing personal and property damage. Properly designed explosion relief valves installed in crankcase doors or covers is one answer to this problem.

ENGINE DEPOSITS

From a practical consideration, engine deposits can be divided into two categories. Those that cause engine malfunctioning and those that do not. While engine cleanliness is a desirable objective, the engine itself is not concerned unless deposits interfere with its normal breathing or digestive functions. Varnish or lacquer films which occasionally form on cylinder walls, piston skirts, crankshafts and connecting rods, for example, do not as a general rule impair engine operation. Actually, such deposits can be beneficial in that they serve as a protective film against rusting or corrosion during periods when engines are out of service.

On the other hand, deposits which accumulate in cylinder ports, on valves, in piston ring grooves and in the combustion chamber are objectionable and if not guarded against can lead to operating troubles. Such deposits result from incomplete fuel combustion combined with lubricating oil decomposition. Accordingly, the formation of objectionable deposits is influenced by:

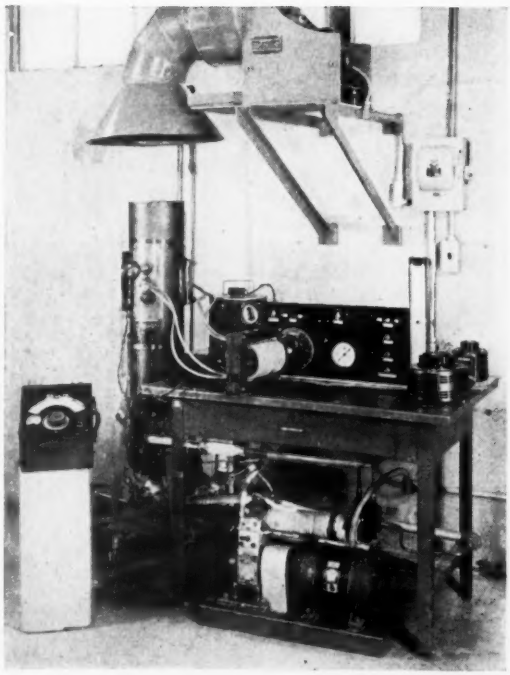

Figure 7—Crankcase Explosion Apparatus

1. Fuel quality.
2. Manner of combustion.
3. Oil quality.
4. Manner of lubrication.

In so far as fuel quality is concerned, what is left after the fuel is burned is the important con-

TABLE G
Ignition Temperatures of Various Oils

	Flash Point COC °F.	*Autogenous Ignition °F.*	*Minimum Ignition °F.*[1]
Naphthene Base Oil			
SAE 10	385	755	1500
SAE 30	395	775	1500
SAE 50	425	810	1500
Paraffin Base Oil			
SAE 10	410	730	1500
SAE 30	490	790	1500
SAE 50	500	795	1500
Heavy Duty Oil			
SAE 10	430	710	1500
SAE 30	440	780	1500
SAE 50	465	815	1500
Heavy Duty Oil Plus			
5% Diesel Fuel	400	780	1500
10% Diesel Fuel	300	730	1500
20% Diesel Fuel	260	735	1500

[1]Determined in explosion tube apparatus shown in Figure 7.

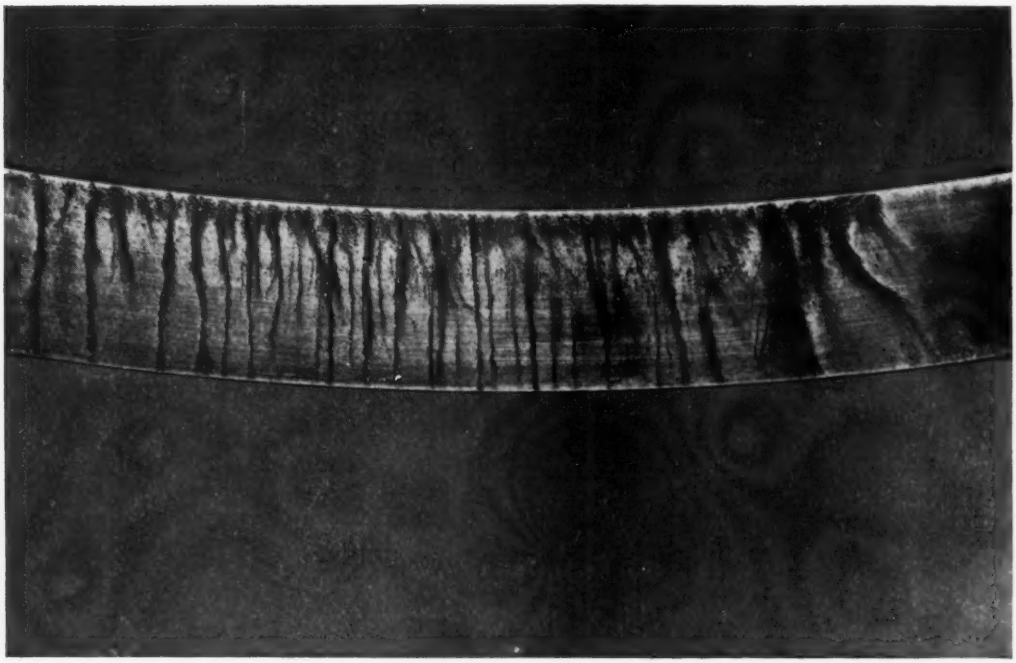

Figure 8—Corroded Piston Ring

sideration. Fuels of high carbon residue and those containing ash materials, i.e. fuels of the residual type leave more deposit forming ingredients behind after combustion than do distillate fuels. While these materials are supposed to go out the exhaust not all of them do. Residual fuels containing vanadium, nickel, sodium and other metallic compounds are particularly bad offenders and it is practically impossible to remove such compounds before the fuel is burned by normal centrifuging or filtering. Table H shows results on a typical heavy fuel containing vanadium before and after having been centrifuged.

TABLE H

Metal	*ppm* *Before Centrifuging*	*After Centrifuging*
Vanadium	390	390
Iron	3	3
Nickel	42	43
Sodium	4	4

Note that there was no reduction in metallic contamination as a result of centrifuging the fuel, which means the metals are combined with other materials, the resulting compounds being soluble in the fuel. Engine deposits containing components originating from residual fuel can be very hard and abrasive. In some cases, it has been found that such deposits are hard enough to scratch steel of as high as 670 Brinnel hardness. This means that deposits of this kind can cause wear of piston rings and cylinder liners if lodged in ports or ring grooves. Lubricating oil also plays a part in formation of objectionable engine deposits. Generally speaking, it is less of a factor than the fuel except where good quality fuel is used and combustion is relatively complete. Notwithstanding, deposit type and quantity is affected by the type of oil used for cylinder lubrication. All things being equal less deposits and those of a soft and fluffy nature are formed with straight mineral naphthene base oils. More deposits, hard and flinty, are formed with straight mineral paraffin oils. While there are cases where additive oils have effected some reduction in engine deposits, such oils have by no means been a cure-all for this problem.

The part that oil plays in the formation of objectionable oil deposits is directly related to the amount of oil delivered by cylinder lubricators to cylinders. To minimize port, ring groove and combustion chamber deposits, lubricators should be set to provide no more than the necessary amount of oil to prevent undue wear of piston rings and cylinders. What this quantity of oil should be is not an easy question to answer and, therefore, it is understandable that sensible practice is to set cylinder lubricators on the conservative side. After all, it is considerably less expensive to clean out engine deposits periodically than it is to renew piston

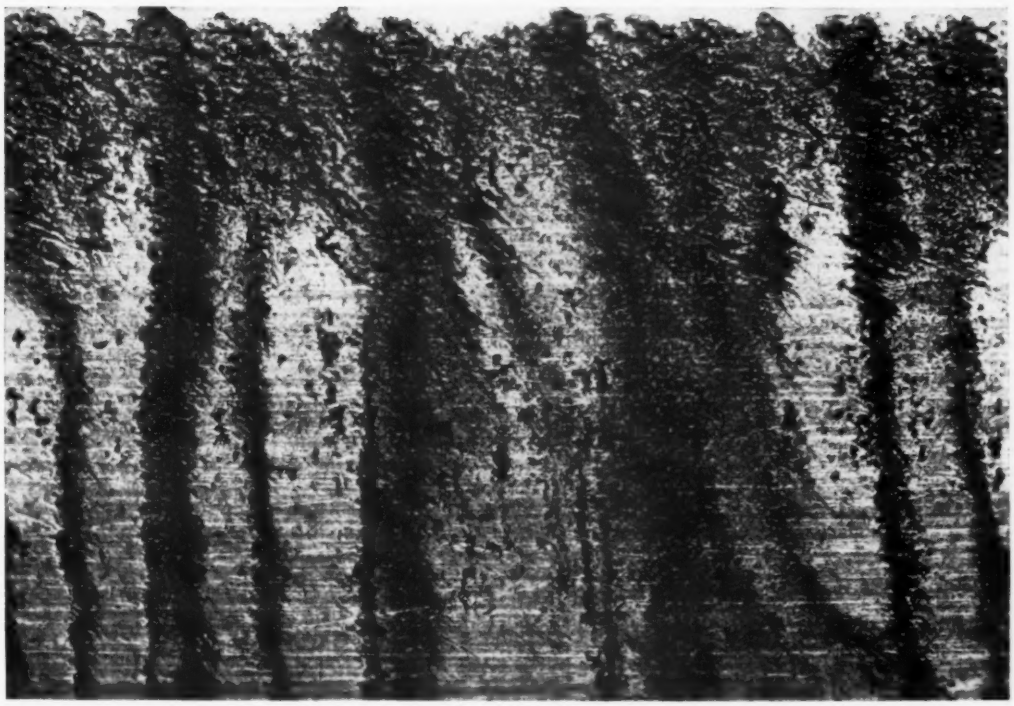

Figure 9 — Magnification of corroded piston ring surface, as shown in Fig. 8.

rings and cylinder liners more often than is absolutely necessary.

Unfortunately, this means in many cases, that more oil is delivered to cylinders than piston rings can handle. The amount of oil beyond that required for satisfactory lubrication has to do something. Accordingly, it stays in ring grooves, passes into the combustion chamber, is blown back through intake ports or out through exhaust ports. At any of these locations there is no further impetus to move the oil so it settles down and stews from the temperature effects of combustion. No oil has yet been developed which can withstand oxidation or decomposition under such conditions.

Elimination of objectionable deposits in large engines particularly those burning heavy residual fuels is a problem which may never be completely solved. Improvements in lubricating oils will help some and better conditions for combustion will help even more. The problem requires continued cooperation of engine builders and oil suppliers for the best interest of operators.

ENGINE WEAR

While difficult to prove statistically, it is probable that wear, i.e., piston ring and cylinder liner wear, in large engines is caused more by corrosion than erosion or abrasion. As the term implies wear due to corrosion means chemical attack of piston ring and cylinder liner surfaces by vapors or acids of one type or another. These corrosive materials form from products of fuel combustion some of which do not have an opportunity to exhaust from the confines of cylinders. The quantities and types of corrosive vapors and acids, mostly the latter because of the condensing effect following the power stroke, produced in the combustion chamber are dependent upon the following factors:

1. Fuel quality.
2. Completeness of combustion.
3. Jacket cooling temperature.
4. Exhaust back pressure.
5. Lubricating oil quality.

For the most part fuel quality and completeness of combustion go hand in hand. Volatility is an important controlling feature, i.e., it is much easier to completely burn gaseous fuels than it is heavy residual oils. Fuel contaminants such as sulfur and nitrogen compounds also can form corrosive materials during combustion particularly in the presence of water vapor. Figures 8 and 9 illustrate an example of chemical attack on piston rings caused by corrosive products of combustion. The ash ingredients, such as sodium, vanadium, iron, etc., in residual fuels are likewise a source of potentially corrosive materials. Maintaining jacket cooling tem-

TABLE J
Cylinder Wear

Cylinder Oil			*Naphthene Oil*				*Paraffin Distillate Oil*				
Cylinder Number	1	2	3	4	5	Avg.	6	7	8	9	Avg.
Wear—Inches (1)	0.006	0.007	0.007	0.006	0.005	0.0062	0.005	0.004	0.003	0.005	0.0042
Wear—Inches (2)	0.004	0.006	0.004	0.005	0.006	0.005	0.005	0.003	0.004	0.003	0.0035
Overall Average						0.0056					0.0039

peratures sufficiently high to prevent condensation of corrosive combustion products on cylinder walls will reduce this type of wear. Likewise being sure that exhaust back pressure is as low as practicable will permit combustion gases to be exhausted without too much interference.

The type of lubricating oil used can influence piston ring and cylinder liner wear due to corrosion. The more highly fortified lubricating oils, such as those complying with Supplement I and Series II requirements, have helped to minimize the effects of sulfur corrosion in engines of certain design. This is one of the reasons why these oils were developed and made available. How well such oils will combat the effects of corrosion resulting from the use of heavy residual fuels has yet to be clarified.

As already indicated ring and cylinder wear is not all due to corrosion. Abrasion and erosion also play a part and both are influenced by many of the same factors that affect corrosive wear including:

1. Air cleanliness.
2. Fuel quality.
3. Combustion chamber deposits.
4. Jacket cooling temperatures.
5. Exhaust back pressure.
6. Lubricating oil quality.

Needless to say it is important to properly filter the intake air to prevent abrasive contaminants from entering the combustion chamber. The same holds true with fuels, particularly those of the heavy residual type, which generally contain water and other contaminants not conducive to good injector lubrication.

The parts played by fuel and lubricating oil quality regarding the formation of combustion chamber deposits and their effects upon ring and cylinder wear have already been covered in the section on Engine Deposits. More can be said about lubricating oil quality, however, as in some large engines, particularly of the two cycle variety, the type of oil used for cylinder lubrication has a direct bearing on ring and cylinder wear. In such cases more wear is experienced with naphthene base oil than paraffin distillate oil of comparable grade. Table J presents cylinder wear figures for one large engine covering six months' full load operation, some of the cylinders having been lubricated with naphthene oil and the remainder by paraffin distillate oil. Note that cylinder wear with the naphthene oil was about one and one-half times as much as that encountered with the paraffin distillate oil. Just why paraffin oils should enable less wear to be encountered in some engines than naphthene oils is not clearly understood at the present time. In all probability, the difference between the two is associated with differences in viscosity and volatility characteristics at temperatures existing on cylinder walls during combustion. Using additive oils for cylinder lubrication of large engines burning gas or a distillate fuel does not, in general, lower ring and cylinder wear.

Jacket cooling temperature, in so far as it governs cylinder wall temperature, influences wear rate not only from the corrosion viewpoint but also from the consideration of formation of deposits in and about the combustion chamber. The higher it is possible to maintain jacket cooling temperatures, the better chance combustion has to be complete and therefore the less likelihood of wear-promoting products, corrosive and/or abrasive, remaining behind to cause trouble. In this connection vapor phase cooling (cooling by evaporation) has been introduced on some large engines as a possible means of more effectively controlling cylinder temperatures. It has been reported that engines so equipped run cleaner without any modification in lubricating oil requirement. While this may be true in many instances, each case should be considered individually to be sure that the proper type and grade of oil is used for cylinder lubrication.

CONCLUSION

This discussion has covered some of the more important problems associated with the lubrication of large gas, dual-fuel and diesel engines. There are, of course, others that have to be taken into consideration when engine builders, operators, and lubrication engineers get together to discuss the best ways to obtain most efficient engine operation. Mutual cooperation among the three groups not only will help to accomplish this objective but also will assist to overcome practical problems connected with engine performance.

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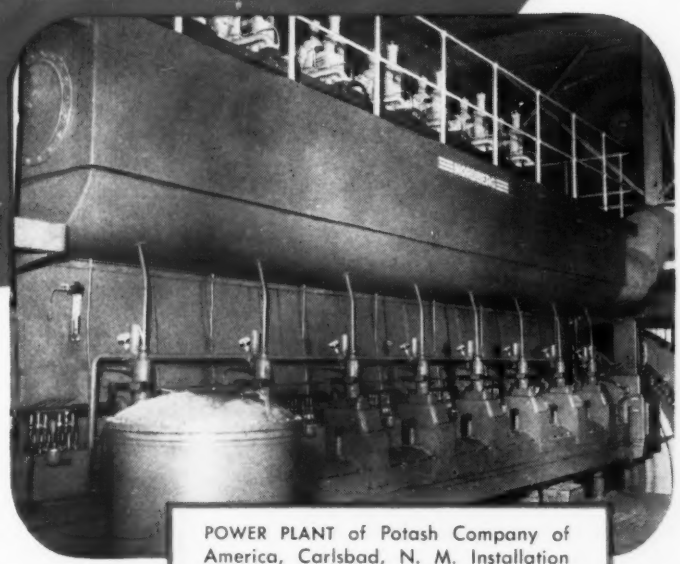
—Denton Smith, Power Plant Superintendent, Potash Company of America, Carlsbad, New Mexico



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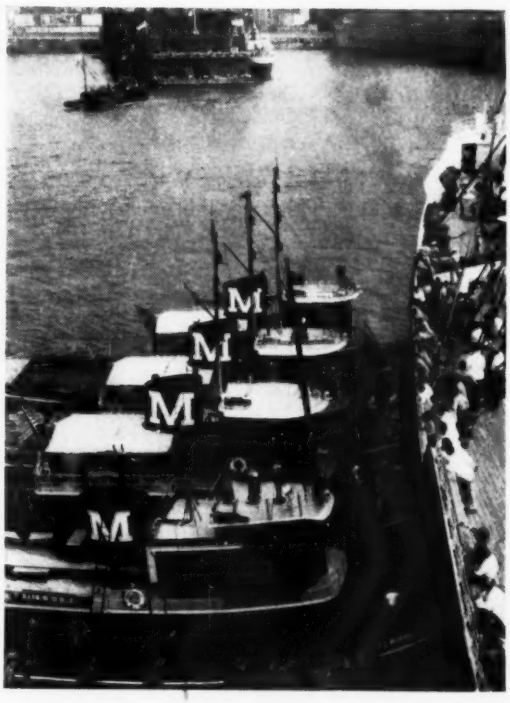

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